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SPECIFIC CHARACTERISTICS OF HIGH-VOLTAGE PULSED CAPACITORS.(U)  
FEB 81 V V KONOTOP, S M FERTIK

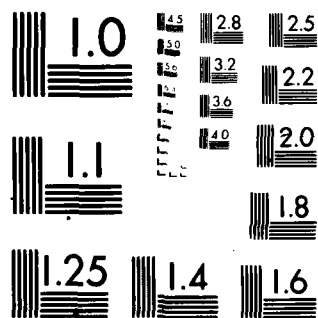
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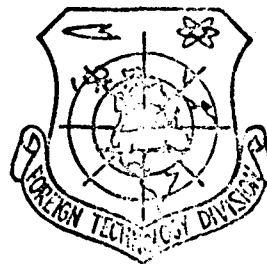


SPECIFIC CHARACTERISTICS OF HIGH-VOLTAGE  
PULSED CAPACITORS

by

V. V. Konotop and S. M. Fertik

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PREPARED BY:

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# U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	<i>А а</i>	A, a	Р р	<i>Р р</i>	R, r
Б б	<i>Б б</i>	B, b	С с	<i>С с</i>	S, s
В в	<i>В в</i>	V, v	Т т	<i>Т т</i>	T, t
Г г	<i>Г г</i>	G, g	У у	<i>У у</i>	U, u
Д д	<i>Д д</i>	D, d	Ф ф	<i>Ф ф</i>	F, f
Е е	<i>Е е</i>	Ye, ye; E, e*	Х х	<i>Х х</i>	Kh, kh
Ж ж	<i>Ж ж</i>	Zh, zh	Ц ц	<i>Ц ц</i>	Ts, ts
З з	<i>З з</i>	Z, z	Ч ч	<i>Ч ч</i>	Ch, ch
И и	<i>И и</i>	I, i	Ш ш	<i>Ш ш</i>	Sh, sh
Й й	<i>Й й</i>	Y, y	Щ щ	<i>Щ щ</i>	Shch, shch
К к	<i>К к</i>	K, k	Ъ ъ	<i>Ъ ъ</i>	"
Л л	<i>Л л</i>	L, l	Ы ы	<i>Ы ы</i>	Y, y
М м	<i>М м</i>	M, m	Ь ь	<i>Ь ь</i>	'
Н н	<i>Н н</i>	N, n	Э э	<i>Э э</i>	E, e
О о	<i>О о</i>	O, o	Ю ю	<i>Ю ю</i>	Yu, yu
П п	<i>П п</i>	P, p	Я я	<i>Я я</i>	Ya, ya

\*ye initially, after vowels, and after ъ, ы; e elsewhere.  
When written as ё in Russian, transliterate as yë or ë.

## RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	sinh <sup>-1</sup>
cos	cos	ch	cosh	arc ch	cosh <sup>-1</sup>
tg	tan	th	tanh	arc th	tanh <sup>-1</sup>
ctg	cot	cth	coth	arc cth	coth <sup>-1</sup>
sec	sec	sch	sech	arc sch	sech <sup>-1</sup>
cosec	csc	csch	csch	arc csch	csch <sup>-1</sup>

Russian      English

rot      curl  
lg      log

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## SPECIFIC CHARACTERISTICS OF HIGH-VOLTAGE PULSED CAPACITORS

V. V. Konotop and S. M. Fertik

Khar'kov Polytechnical Institute imeni V. I. Lenin

Durability [life] is the most important technical and economic indicator of any industrial product, including high-voltage power capacitors.

During a comparative evaluation of various types of capacitors one should necessarily take this factor into account. Let us recall that usually we use so-called specific qualitative characteristics of capacitors which do not take life into account. These include specific weight, unit cost and unit volume which are actual weight  $A$ , cost  $S$  and volume  $V$  of the capacitor referred to its energy index  $E$  [1 and 2]. As the latter factor for power capacitors operating in alternating current circuits, for example, cosine and series capacitors, we use the reactive power of the capacitor  $Q$ , and for

pulsed and filter capacitors, stored energy  $W$ .

Thus, for power capacitors we have:

$$(1) \quad A_{yA} = \frac{A}{\mathcal{A}},$$

$$(2) \quad V_{yA} = \frac{V}{\mathcal{V}},$$

$$(3) \quad S_{yA} = \frac{S}{\mathcal{S}}.$$

Sometimes inverse values are used, for example:

$$(4) \quad \mathcal{A}_{yA} = \frac{\mathcal{A}}{A}.$$

Such specific characteristics, however, are applicable for comparative evaluation of capacitors only in the case when the compared objects have an identical rated life.

Actually this is far from the actual case, in particular for pulsed capacitors which, depending on their designation, are developed for one or another life significantly differing from the accepted average values of the life of power capacitors for general application. Thus, high-voltage pulsed capacitors intended for

physical investigations of powerful magnetic fields or hot plasma are often designed for a total of 1-2 thousand discharges. Along with this capacitors for electrohydraulic installations or for forming lines operating with a repetition frequency of 1-50 Hz must have an average life of  $10^4$ - $10^5$  discharges.

The individual approach to establishing the life of one or another type of capacitor is determined not only by economics but sometimes by purely technical considerations, inasmuch as a decrease of the life makes it possible to correspondingly reduce the weight, volume, and inductance of the capacitor. Therefore for capacitors having a different rated life specific indices must be introduced which take the life into account as well as weight, cost, and volume.

For pulsed capacitors one should take into account the rated and average life (the number of charge-discharge cycles which the capacitor will withstand before failure) and refer a specific characteristic to a single discharge. Then instead of (3) we obtain:

$$(5) \quad a_{yn} = \frac{A}{WN} \left[ \frac{\kappa \tau k_g}{\partial_{mc} \cdot p_{an} p_{wd}} \right]_{J \text{ discharge}}$$

And likewise



$$(6) \quad s_{ya} = \frac{S}{WN} \left[ \frac{\text{table}}{\frac{\partial \text{cost}}{\partial \text{discharge}}} \right]$$

The latter formula is very graphic. It expresses the component cost of a single pulse (discharge) expendable for depreciation of the capacitor referred to the energy stored in the capacitor.

The specific characteristics taking into account the life of a pulsed capacitor could be designated and named:  $a_{ya}$  - specific economic weight,  $s_{ya}$  - specific cost,  $v_{ya}$  - specific economic volume.

Let us examine the suggested specific characteristics in somewhat more detail using the example of pulsed capacitors for general application.

For this we analytically express the specific characteristics of the capacitor through the average life.

For establishing the connection between the average life and the gradient for cosine capacitors in a relatively narrow range with respect to life we use a formula of the form [1]:

$$(7) \quad E = \frac{k_1}{\sqrt{t}}$$

where  $E$  - intensity of the electrical field in the dielectric;

$t$  - average life with a gradient  $E$ ;

$k$  and  $m$  - coefficients, depending on the mode of operation of the capacitor, technology of its manufacture, peculiarities of construction and a number of other factors.

Thus for example, for paper capacitors impregnated with liquid dielectric operating with alternating current,  $m$  may have the values: 7-8 [1], 10 [3], and 12-14 [4]. For capacitors operating with direct current,  $m=16$  [3].

The performed investigations showed that for pulsed capacitors with paper-oil insulation the dependence of the working gradient on the average life may be expressed by an analogous empirical formula of the form [5].

$$(8) \quad E = \frac{k_1}{\sqrt[n]{N}} + E_{\infty}$$

where  $E_{\infty}$  - intensity of the electrical field with which the

capacitor could theoretically operate an infinitely long time; in a narrow range with respect to life we may accept  $E_0 = 0$ .

$N$  - the average life of a capacitor with gradient  $E$ .

As is known the weight of the capacitor in kilograms may be found approximately according to the formula

$$(9) \quad A = 1,13 \cdot 10^{10} \gamma \frac{CU^2}{\epsilon E^2 k_2},$$

where  $E$  - working gradient, V/cm;

$U$  - working voltage, V;

$C$  - capacitance;

$\epsilon$  - relative dielectric constant;

$k_2$  - coefficient of filling of the volume of the capacitor with active dielectric;

$\gamma$  - specific gravity of the dielectric, g/cm<sup>3</sup>.

Coefficient  $k_2$  is equal to the ratio of the weight of the active part of the working dielectric of the capacitor to its total weight and depends both on the parameters of the capacitor (working voltage, capacitance, life) and on the perfection of its construction.

Let us find  $a_{yA}$  for which we substitute (9) into (5):

$$(10) \quad a_{yA} = 2,26 \cdot 10^{10} \gamma \frac{1}{k_2 E^2 N} \left[ \frac{k_2 k_3}{\int \frac{\partial x \cdot \text{распрод}}{\text{discharge}}} \right].$$

Having substituted the value of gradient  $E$  from expression (9) into (10) we will obtain:

$$(11) \quad a_{yA} = 2,26 \cdot 10^{10} \gamma \frac{N^{\frac{2}{m}-1}}{k_1^2 k_2} \left[ \frac{k_2 k_3}{\int \frac{\partial x \cdot \text{распрод}}{\text{discharge}}} \right].$$

In order to move to the specific cost of the capacitor let us note that inasmuch as we use formula (9) and all those following it for comparison of the same type of capacitors which are close to each other in their parameters, then in the first approximation we may consider  $k_2$  as a constant coefficient. Analogously, in the first approximation it is possible to accept that the supply cost of the capacitor is proportional to the weight of the active part of the dielectric. As shown by the cost analysis of a number of domestic

capacitors, the corresponding proportionality coefficient  $k$ , lies in the limits of 0.15 to 0.4.

Then

$$(12) \quad s_{y\Delta} = 2,26 \cdot 10^{10} \gamma \frac{N^{\frac{2}{m}-1} P_1}{k_1^2 k_{1a}} \left[ \frac{1}{\partial \text{ж} \cdot \text{разр} \partial} \right],$$

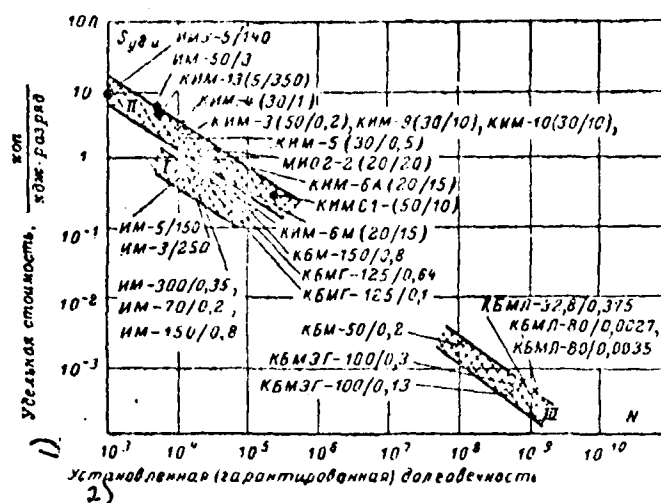
KEY: rubles/J•discharge.

where  $P_1$  is the cost of the dielectric, rubles/kg.

It would be possible to write more accurate and more complex equations expressing the dependence of the total weight and the supply cost of the capacitor on the weight of the active part of the working dielectric. However, for the given qualitative investigation this is apparently not required, especially as the value  $K_3$  is affected by a number of other factors which are difficult to consider (technological effectiveness of the construction, degree of mechanization of production, level of additional expenses, etc.).

Let us examine expression (12). From it, it follows that other conditions being equal the calculated  $s_{y\Delta}$  decreases in proportion to the increase of  $N$ .

On the basis of analysis of the wholesale cost of capacitors of type IM produced by domestic plants, and also of capacitors produced in small series at the Khar'kov Polytechnical Institute, depending on the rated (guaranteed) life, the figure shows plotted curves.



Dependence of the specific cost of discharge on the rated life of the capacitor.  $\circ$  - area I;  $\Delta$  - II;  $\times$  - III. KEY: 1. specific cost, copecks/kV·discharge; 2. rated (guaranteed) life.

Values of coefficients  $m$  and  $k_1$  for capacitors turned out to equal: for area I,  $m=9$  and  $k_1=2.5 \cdot 10^6$ ; for area II,  $m=11$  and  $k_1=1.1 \cdot 10^6$ ; for area III,  $m=8$  and  $k_1=1.6 \cdot 10^6$ .

The same figure shows the specific cost of some types of

capacitors with insulation of capacitor paper impregnated with capacitor oil.

These curves enclose three areas:

Area I encompasses pulsed capacitors operating at an equivalent load of more than  $1 \Omega$ , with a discharge repetition frequency not greater than 0.1-0.01 Hz (for example, circuits of generators of pulsed voltage and current in high-voltage electrical engineering laboratories, and some electrohydraulic installations).

Area II encompasses pulsed capacitors operating at very small equivalent loads on the order of 0.01-0.1  $\Omega$  (installations for some physics research, for magneto-pulse treatment of metals, and so forth). The repetition frequency is usually not greater than 0.1 Hz.

Area III - capacitors discharging to loads on the order of 10 ohms with a repetition frequency of 25-100 Hz (circuit of high-voltage forming lines, some electrohydraulic installations, etc.).

It should be considered that the average life of a capacitor is usually not less than 2-3 times higher than the rated (guaranteed) life.

The relationships given above apparently relate to the case when capacitors are always operated under nominal conditions with respect to charge voltage and load. If under actual conditions, as this often happens, the capacitor is used with various values of the charge voltage  $U \leq U_H$ , then its work capacity will naturally increase.

Normally the operation of a capacitor is provided for at several different (discrete) operating voltages  $U_1, U_2, \dots, U_k, \dots, U_H$ , to which corresponds a life  $N_1, N_2, \dots, N_k, \dots, N_H$ . If at each voltage the capacitor operates  $p$  % of the time so that  $p_1 + p_2 + \dots + p_k + \dots + p_H = 100$  % , then the rated life of the capacitor is increased and will apparently be equal to:

$$(13) \quad N_H = \frac{100}{\sum_{k=1}^n \frac{p_k}{N_k}},$$

where  $N_p$  - rated life of the capacitor taking into account the charging conditions in the given installation.

Taking into account that for a pulsed capacitor a relationship of the form



$$(14) \quad \left(\frac{U_k}{U_n}\right)^m = \frac{N_k}{N_n},$$

is valid, and substituting (15) into (14) we obtain

$$(15) \quad N_p = \frac{100 N_n}{\sum_{k=1}^n p_k \left(\frac{U_k}{U_n}\right)^m},$$

where  $N_n$  - rated life at the nominal voltage.

The relationships given above may be used by developers of high-voltage pulsed capacitors and designers of high-voltage pulsed installations for technological purposes and for scientific research.

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